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Composites, Fabrication to Die Design

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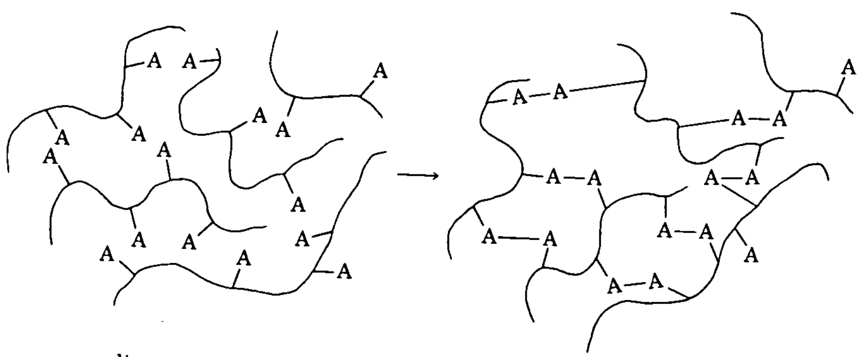
CROSS-LINKING

Cross-linking reactions are those that lead to the formation of insoluble and infusible polymers in which chains are joined together to form a three-dimensional network structure (1,2). A simple cross-linking reaction is exemplified by polymer chains with several functional groups designated A that are capable of reacting among themselves to form chemical bonds A—A. If these polymer chains are exposed to conditions such that the functional groups do react, then all the chains in the reaction vessel will be tied to each other through A—A bonds. In principle, the polymer molecules in the reaction vessel will have formed one giant molecule.



linear polymer cross-linked polymer

Cross-linked polymers differ in many important respects from linear and branched polymers. For example, they swell in a good solvent to form a gel but do not dissolve to form a solution. At elevated temperature, cross-linked polymers generally behave like soft but elastic solids rather than viscous liquids (3). Vulcanized rubber is one familiar example (4).

The vulcanization process involves cross-linking reactions that make rubber useful in applications where mechanical strength is important. Other cross-linked polymers are widely used in paints, printing inks, adhesives, sealants, encapsulants, and electrical and electronic components. Phenol–formaldehyde resins, epoxy resins (qv), amino resins (qv), polyurethanes (qv), unsaturated polyesters, alkyd resins (qv), silicones (qv), polyimides (qv), and acrylics are some commercially important cross-linked materials (see also PHENOLIC RESINS; POLYESTERS, UNSATURATED). These polymers are also called thermosets or network polymers and the cross-linking process is referred to as vulcanization (qv), curing (qv), thermosetting, or network formation (see also GELS; INTERPENETRATING POLYMER NETWORKS; NETWORKS).

In the example above, the macromolecules were self-reacting, but this is not necessary for network formation. Cross-linking can be carried out through the use of a cross-linking agent, a molecule that has two or more groups capable of reacting with the functional groups on the polymer chain: